Mechanical characterization of re-used vulcanized rubber

Caracterización mecánica del caucho vulcanizado reciclado

Juan Fernando López[1]

Abstract

Rubber is an important material in factory for manufacturing vehicles parts and electric industry components. There are thousands of tons of vulcanized rubber waste due to cars' tires, shoes, electric components, o- rings, rubber seals, etc. which every day are disposed in landfills causing a severe environmental damage. In specialized literature there are many alternatives to rubber recycling, some of them mechanical, other chemicals. However, most of them expensive because the process of rubber recycling is very difficult, and there is not an effective and industrial recycling technique. This paper shows the mechanical characterization of rubber re-vulcanized test pieces, using several

1. Universidad Católica de Pereira, juan5.lopez@ucp.edu.co

compositions mixing raw and vulcanized crumb rubber. This study shows the increase of tensile modulus when homogenization is achieved.

Keywords: Crumb rubber, Mechanical characterization

Resumen

El caucho es un material importante en la fabricación de autopartes y componentes de la industria eléctrica. En la actualidad existen miles de toneladas de desechos de caucho vulcanizado debido a las llantas de los automóviles, suelas de zapatos, componentes eléctricos, empaquetaduras, sellos de caucho, etc. que todos los días son desechados en vertederos provocando un severo daño ambiental. En la literatura especializada existen muchas alternativas para el reciclaje del caucho, algunas mecánicas, otras químicas. Sin embargo, la mayoría de ellas son costosas porque el proceso de reciclaje del caucho es muy difícil y no existe una técnica de reciclaje industrial eficaz. Este trabajo muestra la caracterización mecánica de piezas de caucho re-vulcanizado, utilizando varias composiciones que mezclan caucho virgen y caucho vulcanizado triturado. Este estudio muestra el incremento del módulo de elasticidad cuando se logra la homogeneización.

Palabras Clave: Caucho vulcanizado, Caracterización mecánica

Introduction

Natural Rubber comes from the rubber tree as a white latex and after vulcanization It has many industrial applications such as o-rings, shoes, electric components, flexible piping, tires, etc. However, every industrial process in rubber transformation brings some amount of waste. The most visible problem with rubber is the tire production. Every tire is made from a mixture of natural and synthetic rubber with more than 100 different chemical components. The previous scenario shows a problem of general pollution and waste disposal.

In the city of Pereira, Colombia, in 2015, is estimated that 448.879 tires were discarded. 249.887 were converted into special solid waste, numbers tending to increase, due to the growth in the automotive fleet in recent years. The city cleaning company cannot handle tires accord to legislatives that does not include tires in the characterization of ordinary waste in Pereira, added to the complexity involved in its handling, recycling and decomposition. Most of this recycling is accomplished transforming the vulcanized rubber in Asphalt concrete (black-top, bitumen or rolled asphalt) or shredding to small parts for synthetic soccer fields.

There are several strategies for vulcanized rubber reusing, as can be seen in the works of Ciesielski (2009), Martin (2014) and Sadhan (2005), who established chemical methods to recover the vulcanized rubber and desulfurize the material. The specialized literature in materials (Ashby, 2014), (Kalpakjian, 2008), (Smith, 2006), specifies how rubber changes its molecular structure when vulcanized and this is the main challenge to overcome in a system of rubber reuse. The other approach to this reuse is the mechanical transformation of the waste in other industrial design products (Ashby, 2014) using different manufacturing processes or binders to carry out processes for shaping the rubber chip or pellets. Recent studies show how to obtain a crumb rubber with a particle size of 100 to 150 micrometers using ultrasonic grinding (Dobrotă & Dobrotă, 2018) this rub-ber granulate can be treated as a raw material for composites, polymers (Sienkiewicz et al., 2017) (Cazan et al., 2019) concrete aggregates (Saberian & Li, 2018), asphalt or chip seal (Gheni et al., 2017), (Gheni et al., 2018), etc.

Besides this research in the field of rubber reusing, there is not much information concerning the rubber re-vulcanization with granulated aggregate and its mechanical properties. This paper shows the mechanical properties of crumb rubber mixed with natural rubber for revulcanization. Two different granulate sizes are used and hardness, compression and tension tests are achieved.

Materials and methods

Test pieces

Several test pieces were fabricated with different composition of natural and vulcanized rubber. For this purpose, natural rubber 65 is mixed with rubber burr and crumb rubber. The configurations considered for specimen's construction are specified in Table 1.

Table 1. Test pieces compositions

Piece Number	Code	Natural Rubber (% in weigth)	Vulcanized Rubber (%in weigth)	Observations
1	100VU	0	100	Vulcanized Rubber: Burr from pieces of natural rubber
2	20VR80VU	20	80	
3	40VR60VU	40	60	
4	60VR40VU	60	40	
5	80VR20VU	80	20	
6	40VR60VULL	40	60	Vulcanized Rubber:
7	60VR40VULL	60	40	Crumb Rubber

Source: Authors

The specimens were made by means of transformation of the virgin rubber and recycled rubber mixtures, through a vulcanization process, based on special characteristics according to the ASTM test standards for determination of mechanical properties. The specimens for tensile test have a double bell shape (Figure 2) with L = 30 mm and the specimens used for hardness and compression tests have a standard cylindrical shape (Figure 2) with diameter d = 29 ± 0,5 mm and height h = 12.5 ± 0.5 mm. For each configuration, 3 specimens were obtained to be subjected to traction and 3 for compression tests.

Figure 1.

Tensile test piece. (IS, 2012), Source: Authors

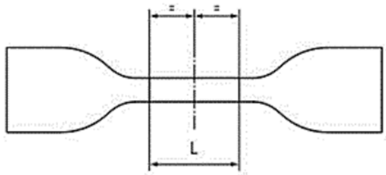
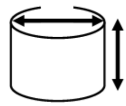


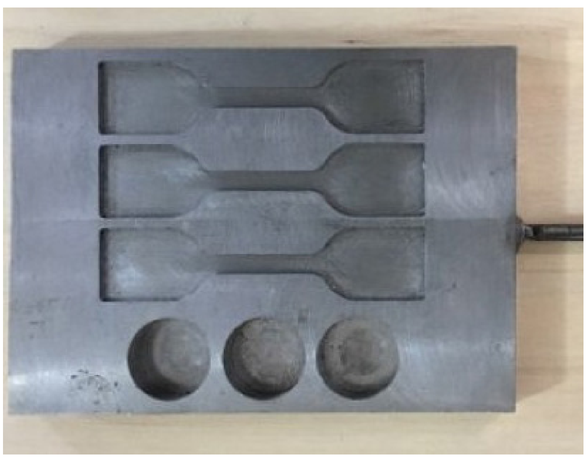
Figure 1.

Hardness and compression test piece. Source: Authors



For creation of specimens, a mold in AISI-SAE 1020 steel is fabricated (Figure 3), which is installed in the press for the transformation of the rubber mixtures through traditional vulcanization process.

Figure 2. *Mold for test pieces manufacturing Source: Authors*



Methods

Material tests: To determine the mechanical properties of rubber mixtures, the mechanical tests achieved on the rubber specimens will serve as a basis for characterizing the behavior of the material when it is subjected to mechanical stress. The conditions for each of the tests accomplished on the manufactured specimens are shown in Table 2.

Table 2. *Standards used for testing rubber samples*

Test	Standard	Number of pieces	Description
Hardness	DIN 53505	3	Shore Hardness A. This test is implemented in compression piece. A 1kg mass is used in the test.
Compression	ISO7743:2017	3	Constant speed load is applied at 10 mm/min until 25% deformation is reached. The piece is released at the same speed. The cycle is repeated 4 times.
Tensile	IS3400:2012	3	0.1MPa preload. Constant speed load is implemented of 200 mm/min until specimen crash.

The Shore A hardness test was carried out under standard DIN 53505 at 20 ° C, one week after vulcanization of the test specimens. For each of them, at least 3 marks were made at different points on the surface, separated at least 5 mm from each other and from the edges. When making the measurements, the apparatus exerted an approximate load of 1 kg (9.81 N) on the surface of the test pieces. Each reading was made after 3 seconds of load execution. The experimental setup of the test is shown in Figure 4.

Figure 4

Shore A hardness test set up. Source: Authors

Figure 5

Compression test set up. Source: Authors

Hardness, compression and tensile tests were achieved in materials resistance laboratory in Universidad Tecnológica de Pereira, for compression test is used a universal test machine according to standard specification. For tensile test, a Mark 10 Force Test Stand is applied as shows figures 5 and 6

Figure 6. *Tensile test set up. Source: Authors*

Results and discussion

According to the standard, three specimens were tested, and the overall mean is presented in this paper. Table 3 shows results for 100% natural virgin rubber. Table 4 summarizes the hardness mean value and variance results for each material combination.

Table 3. *Hardness results for 100% natural rubber test piece*

	Hardness 1	Hardness 2	Hardness 3	Mean
specimen 1a	55.5	57.5	57.0	56.7
specimen 1b	59.0	58.5	59.0	58.8
specimen 1c	57.5	58.0	56.0	57.2
Shore A Hardness (Test piece 1 – 100VR)				57.6

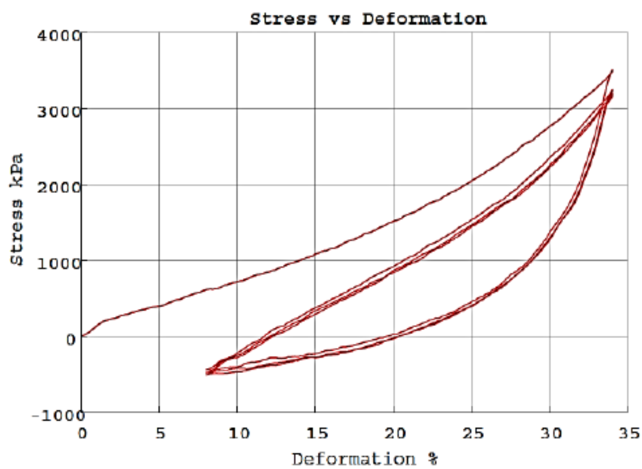
Table 4. *Hardness test results*

Test piece / Shore A Hardness	Hardness mean value	Results Variance
Piece 1 – 100VR	57.6	
Piece 2 – 80VR20VU	58.4	
Piece 3 – 60VR40VU	51.7	
Piece 4 – 40VR60VU	54.4	
Piece 5 – 20VR80VU	57.6	
Piece 6 – 40VR60VULL	52.6	
Piece 7 – 60VR40VULL	50.2	

Compression results

In compression test, the Young Modulus was calculated from 4 load cycles. Figure 7 shows stress vs deformation graph. Most of the rubber application are in the scope of compression forces therefore this test is important for practical applications.

Figure 7. *Stress vs Strain curve for compression test in test piece 1.*



From this curve is possible to calculate a Young modulus in compression. The machine test actually measures force and deformation, the stress and proportional deformation are calculated with eq 1 y eq 2.

$$\sigma = \frac{F}{A_0} \quad (1)$$

Since σ is the stress calculated, A_0 is the transversal specimen area and F is the force measured in the Universal test machine.

$$\varepsilon = \frac{\Delta L}{L_0} * 100 \quad (2)$$

Since ε is the strain calculated, ΔL is the specimen length variation and L_0 is the initial length of the test piece.

Table 5 shows the unitary deformation ε, the maximum stress σ_max and the Young´s Modulus in compression.

Table 5. *Compression test results*

Test piece	ε	σmax (kPa)	E(MPa)
Piece 1 – 100VR	0.3406	3009.86	12.2658
Piece 2 – 80VR20VU	0.34084	2130.67	6.2653
Piece 3 – 60VR40VU	0.34037	2188.83	8.9886
Piece 4 – 40VR60VU	0.34064	1859.83	5.4646
Piece 5 – 20VR80VU	0.34059	897.81	2.6332
Piece 6 – 40VR60VULL	0.3399	2065.44	6.0885
Piece 7 – 60VR40VULL	0.33866	2191.58	6.43

Source: Authors

3.2. Tensile test results.

The principal result of tensile test is the Young Modulus which permits the comparison of this material with others, also, this result gives a clue in the possible application of the mixture vulcanized rubber.

Figure 8 shows the stress strain curve for all test pieces in different color with a typical characteristic curve for rubber materials.

Figure 8. *Stress vs Strain for tensile test.*

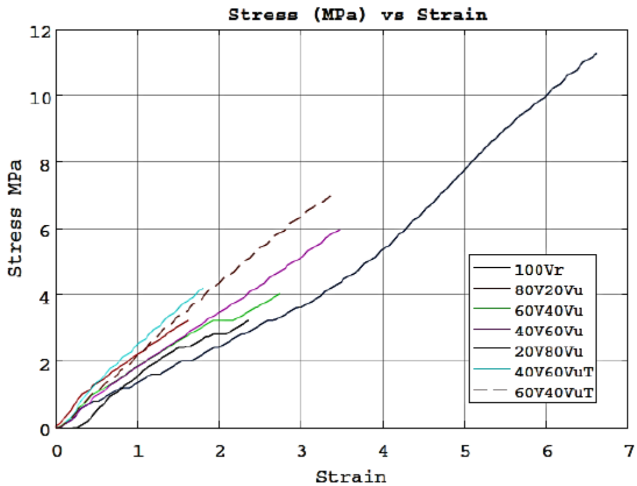


Table 6 summarizes the tensile test results for different test pieces. The table shows the unitary deformation ε, the maximum stress σ_max and the Young´s Modulus E.

Table 6. *Tensile test results*

Test piece	ε	σmax (kPa)	E(MPa)
Piece 1 – 100VR	0.661	11.27	1.70
Piece 2 – 80VR20VU	0.320	6.83	1.79
Piece 3 – 60VR40VU	0.359	5.24	1.46
Piece 4 – 40VR60VU	0.346	5.96	1.72
Piece 5 – 20VR80VU	0.215	3.22	1.49
Piece 6 – 40VR60VULL	0.180	4.21	2.33
Piece 7 – 60VR40VULL	0.529	9.79	1.85

Source: Authors

Discussion

The principal characterization of rubber for practical applications is the hardness number, even you can find several charts that localize de rubber products according to Shore number. In the focus of this research the Rubber used in the factory CADELI, is meanly applied in electrical elements, o-rings and automotive parts. With the Shore A test a Hardness between 50 and 58 was found in the overall material tested. Having a decrease in hardness in the mixture with the crumb rubber, compared with the 100% virgin rubber. From application point of view those test pieces are between medium soft and medium hard rubber. This means that harder ones (test piece 1 and

2) works for applications in tires and automotive parts. Piece 5 is medium hard, but in the test piece It is not possible to obtain a homogenous mix between virgin and vulcanized rubber, also, due to the size of the granulated waste rubber, the hardness test often shows the characteristic of only this part of the mixture.

Conclusions

It is found that the crumb rubber allows a better homogenization with the virgin rubber meanwhile decrease the compound hardness.

In general, the mechanical properties of Rubber decrease with the amount of chopped rubber and crumb rubber added. From tables 5 and 6 it can be shown that chopped waste rubber maintains better the compression strength and crumb rubber maintain better the tensile compound strength.

From this, in applications as floors, shock absorbers and compression parts, it should be used chopped rubber mixed with virgin rubber. And for application such as elastic bands, and tensile parts, the crumb rubber should be better. However, each application of this recycled material should be tested before to avoid problems with product quality.

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